Marooned on an Extinct Volcano: the Conservation Status of Four Endemic Land Snails (Gastropoda: Pulmonata) at Mount Kaputar, New South Wales

MICHAEL J. MURPHY[1], JESSICA K. MURPHY[2], C. JAMES FARIS[3] AND MICHAEL J. MULHOLLAND[4]

[1] NSW National Parks and Wildlife Service, PO Box 952 Moama NSW 2731;
[2] Forsyth Street Wagga Wagga NSW 2650;
[3] NSW National Parks and Wildlife Service, PO Box 72 Narrabri NSW 2390;
[4] NSW National Parks and Wildlife Service, PO Box 848 Narrabri NSW 2390

Published on 13 October 2019 at https://openjournals.library.sydney.edu.au/index.php/LIN/index

Murphy, M.J., Murphy, J.K., Faris, C.J. and Mulholland, M.J. (2019). Marooned on an extinct volcano: the conservation status of four endemic land snails (Gastropoda: Pulmonata) at Mount Kaputar, New South Wales. *Proceedings of the Linnean Society of New South Wales* **141**, S33-S44.

Volcanic activity in northern inland New South Wales between 40 and 15 million years ago was followed by general continental-scale drying and coastward contraction of mesic ecosystems between 15 and 2 million years ago. Together, these processes resulted in the creation of high-elevation climatic refuges such as Coolah Tops, Mount Kaputar and the Warrumbungle Range as western outposts of the mesic eastern highlands on the dry western slopes. These areas are important hotspots of land snail species diversity and endemism. A high-elevation and dry rainforest land snail community at Mount Kaputar, recognised as being of outstanding conservation significance, was listed as an endangered ecological community under NSW legislation in 2013. Two species from this community, the Kaputar Pink Slug *Triboniophorus* sp. nov. "Kaputar" and Bronze Rippled Pinwheel Snail *Cralopa kaputarensis*, are currently listed on the *IUCN Red List*, as *endangered* and *data deficient* respectively. This paper provides an updated assessment of the conservation status of the Kaputar Pink Slug, a reassessment of the Bronze Rippled Pinwheel Snail and original assessment of another two endemic Mount Kaputar species (Kaputar Carnivorous Snail *Vitellidelos kaputarensis* and Kaputar Keeled Snail *Thersites* sp. nov. "Kaputar"), concluding that all four species meet the criteria for listing as *endangered* on the *IUCN Red List*.

Manuscript received 15 April 2019, accepted for publication 5 August 2019.

Key words: climate change, conservation assessment, endangered land snails, IUCN Red List, Kaputar Pink Slug, Mount Kaputar.

INTRODUCTION

Wildlife conservation efforts often focus on vertebrate fauna, which represent just 1% of faunal species diversity. Eastern mainland Australia has a rich native land snail fauna estimated at more than 1250 species in 25 families (Stanisic and Ponder 2004; Stanisic et al. 2010; Stanisic et al. 2017). The most species-rich families are the Charopidae, Camaenidae and Helicarionidae. About 90% of species occur in rainforests, where long-term moisture stability and complex microhabitats have supported the evolution and survival of diverse land snail communities, while relatively few species occur in drier eucalypt forests (Stanisic 1994). Rocky habitats providing moisture and shelter are also important, particularly in arid and semi-arid areas (Slatyer et al. 2007; Stanisic et al. 2017). Identifying and protecting hotspots of species diversity and endemism is a high priority for land snail conservation (Ponder 1997; Parkyn and Newell 2013).

Volcanic activity in northern inland New South Wales (NSW) 40 to 15 million years ago (Sutherland 2011) was followed by general continental-scale drying and coastward contraction of mesic ecosystems between 15 and 2 million years ago (Martin 2006). This resulted in the creation of high-elevation climatic refuges such as Coolah Tops, Mount Kaputar and the Warrumbungle Range as western outposts of the mesic eastern highlands on the dry western slopes.

These isolated high-elevation areas are hotspots of land snail species diversity and are notable exceptions to the general pattern in eastern Australia of land snail species diversity decreasing with distance from the coast (Stanisic 1994). Hyman and Stanisic (2005) noted the refugial significance of these sites in land snail evolution. The refuge sites support distinct land snail communities including narrow-range endemic species such as *Austrorhytida warrumbunglensis* (Rhytididae), *Austrochloritis warrumbunglensis* (Camaenidae) and *Ponderconcha warrumbungliana* (Camaenidae) in Warrumbungle National Park (NP) (Shea 1992; Stanisic et al. 2010), and *Austrochloritis liverpoolensis* (Camaenidae), an undescribed *Thersites* species (morpho-species code Camaenidae SN30) and an undescribed rhytidid (Rhytididae SN7) in Coolah Tops NP (Murphy unpublished data). Mount Kaputar NP is the best-studied site to date, supporting a native land snail fauna of 24 species (seven families) including nine endemic species (Murphy and Shea 2015).

A high-elevation and dry rainforest land snail community at Mount Kaputar is considered to be of outstanding conservation significance and was listed as an endangered ecological community under the NSW *Threatened Species Conservation Act 1995* in December 2013 (Murphy and Shea 2015), and subsequently under the NSW *Biodiversity Conservation Act 2016*. Eighteen native land snail species are currently known from this community of which eight are endemic to the community (Murphy and Shea 2015). Two of these endemic species, the Kaputar Pink Slug *Triboniophorus* sp. nov. "Kaputar" (Athoracophoridae) and the Bronze Rippled Pinwheel Snail *Cralopa kaputarensis* (Charopidae) have been previously assessed by the International Union for Conservation of Nature (IUCN), with the former listed as *endangered* (Murphy 2014) and the latter as *data deficient* (Mollusc Specialist Group 1996) on the *IUCN Red List*. The current paper presents an updated version of the Kaputar Pink Slug conservation assessment, a reassessment of the Bronze Rippled Pinwheel Snail and novel assessments for another two endemic species. The four species have overlapping distributions and face similar threats and, to avoid repetition, the four assessments are presented in combination.

STUDY AREA

Mount Kaputar NP (30° 16' S, 150° 10' E) (Fig. 1) is about 51340 ha in area and is located near the town of Narrabri in Gamilaraay Aboriginal Country in northern inland NSW, 270 km from the Australian east coast on the western inland slopes of the Great Dividing Range. The majority of the park is in the Nandewar bioregion, extending into the Brigalow Belt South bioregion along parts of the park's western margin. The park's landscape comprises the eroded remains of the Nandewar Volcano, a mid-plate alkaline shield volcano dating from the early Miocene (18-19 million years ago) (Sutherland 2011) and now reaching a maximum elevation of 1508 m Australian Height Datum (AHD). The local climate is strongly influenced by elevation, with temperatures differing by up to 12° C between lowland and upland areas and average annual rainfall varying from 800 mm in lowland areas to 1200 mm in upland areas (Hunter and Alexander 2000). The vegetation varies with elevation and topography, including areas of sub-alpine open forest of Snow Gum *Eucalyptus pauciflora*, Ribbon Gum *E. viminalis* and White Gum *E. dalrympleana* (Myrtaceae) above about 1350 m AHD and small patches of dry rainforest with Rusty Fig *Ficus rubiginosa*, Sandpaper Fig *F. coronata* (Moraceae) and Native Olive *Notelaea microcarpa* (Oleaceae) in rocky gullies topographically sheltered from wildfire, at elevations down to less than 500 m AHD (Porteners 1997, 1998; Hunter and Alexander 2000). The endangered land snail community at Mount Kaputar occurs in high elevation areas above 1000 m AHD (an area of about 107 km^2) and in small dry rainforest remnants at lower elevations (estimated to total less than 1 km^2) (Murphy and Shea 2015).

ASSESSMENT METHODS

Species records were collated from systematic field sampling of land snails at 36 sites in Mount Kaputar NP in 2007-2014, a 2.7 km transect survey for slugs in 2011 and data from the collections of the Australian Museum and Queensland Museum (Murphy and Shea 2015), augmented by additional opportunistic field records collected by the four authors over the period 2015-2018 and opportunistic records provided by other local staff. The conservation status of each species was assessed using the *IUCN Red List* criteria (IUCN 2012; IUCN 2017). Estimating population size is difficult for land snails, due to weather-dependent variability in activity. Conservation assessment therefore focussed on criterion B (Geographic Range). In recognition of the incomplete field survey coverage of Mount Kaputar NP (Murphy and Shea 2015), extent of occurrence (EOO) was estimated as a minimum convex polygon enclosing all actual known sites of the species

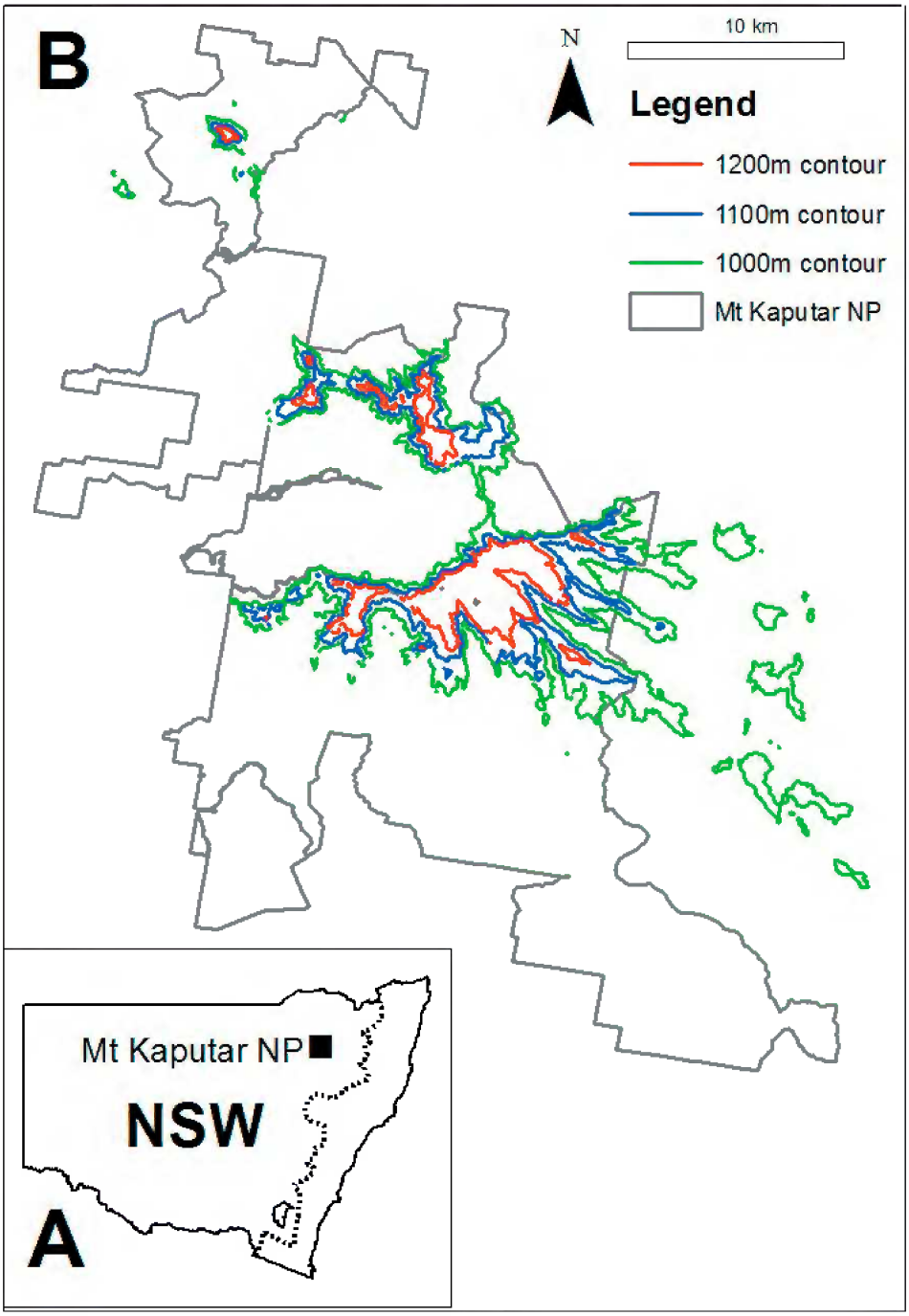

Fig 1. Mount Kaputar NP. Map A, location of the park in northern inland NSW west of the Great Dividing Range (shown by dotted line). Map B, distribution and extent of high elevation areas in the park.

Fig 2. The four subject species. A, Kaputar Pink Slug. Photo: M.J. Murphy. B, Bronze Rippled Pinwheel Snail. Photo: V. Railton. C, Kaputar Carnivorous Snail. Photo: M.J. Murphy. D, Kaputar Keeled Snail. Photo: M.J. Murphy.

together with inferred sites based on habitat mapping. Habitat was mapped by delineating all highland areas at or above the lowest recorded highland occurrence of the species (rounded down to the closest 100 m). Area of occupancy (AOO) was estimated using a 2 x 2 km grid (in GDA94 Zone 56) over a map of Mount Kaputar NP showing known sites and mapped highland habitat areas together with satellite imagery of vegetation cover. Any highland areas on freehold properties adjacent to the park that have been cleared for agriculture were excluded from AOO estimates as being unlikely to be occupied by the species. Grid squares including either known sites or mapped high elevation potential habitat were tallied. The number of locations for each species was assessed, using the IUCN definition of a location as a geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present (IUCN 2017). The entire Mount Kaputar highland area is threatened by a single event (anthropogenic global warming) and was therefore considered to be one location. Individual lowland dry rainforest sites supporting the species that were disjunct from the highland area were considered to be separate locations.

TAXONOMY, DISTRIBUTION AND ECOLOGY

Kaputar Pink Slug *Triboniophorus* sp. nov. "Kaputar"

The Kaputar Pink Slug (Fig. 2A) is a large bright pink slug with white sole and optic tentacles and is a member of the Gondwanan slug family Athoracophoridae. Members of this family occur in the south-western Pacific including eastern Australia, New Guinea, New Caledonia, Vanuatu, New Zealand and some sub-Antarctic islands (Burton 1980; Smith

Fig 3. Feeding trail of Kaputar Pink Slug. Photo: M.J. Murphy.

1992; Stanisic et al. 2010). A taxonomic review by Gary Barker (pers. comm. in Murphy and Shea 2015) determined the Kaputar Pink Slug to be a distinct undescribed species endemic to Mount Kaputar. Voucher material is available in museum collections (e.g. AMS C.104019, AMS C.107910, AMS C.168560, AMS C.331977, AMS C.403799 (Australian Museum, Sydney) and QM MO32871 (Queensland Museum, Brisbane)). The slug is the only member of the Athoracophoridae found inland of the Great Dividing Range in Australia, with a distance of about 170 km separating the Kaputar Pink Slug from the nearest *Triboniophorus graeffei* populations east of Glen Innes and Armidale on the New England Tableland (Atlas of Living Australia). The previous IUCN assessment of the species (Murphy 2014) was based on a dataset of 40 records. An additional 113 records were collated for this updated assessment, including some from remote Wilderness areas. All records of the Kaputar Pink Slug are from areas above about 1000 m AHD at Mount Kaputar, with the exception of a single record from about 550 m, in streamside rainforest contiguous with the highland area.

The slugs shelter under leaf litter, woody debris and loose rocks during dry conditions. On rainy nights they emerge and crawl over rock outcrops and shrubs and climb tree trunks to heights of 20 m or more, feeding on the biofilm of micro-algae, lichen and fungi growing on the surface of rock faces and eucalypt bark and leaving characteristic feeding trails (Fig. 3). The slugs generally return to shelter in the morning, moving at about 10-20 cm/minute (Murphy and Shea 2015), but under suitably mild and cloudy conditions can continue activity into the afternoon. Predation of the slugs by diurnal birds appears to be rare but includes the Laughing Kookaburra *Dacelo novaeguineae* (Alcedinidae) and Pied Currawong *Strepera graculina* (Artamidae) (Fig. 4).

Apparent abundance of the species is very weather dependent. Sixty-three slugs were counted in 10 minutes along a 200 m walked transect along the edge of a roadside rock cutting on a mild night with light rain in November 2010, and on the following night under dry conditions only two slugs were seen on the same transect (Murphy and Shea 2015). This transect was surveyed again in the mid-afternoon on a rainy day in April 2015 and 103 slugs were counted. In dry weather slugs are inactive and are difficult to find even by hand searching of shelter sites. Feeding trails are a reliable indicator for the species in the absence of active animals.

A pilot study at a site near the Mount Kaputar summit in April 2015 examined the sinuosity of slug feeding trails on eucalypt tree trunks. Although no significant correlation between sinuosity and heights of between 1 and 3 m on tree trunks was found (Spearman's correlation test $P > 0.05$, rho = 0.066), this brief study demonstrated the feasibility and potential value of using feeding trails as an indirect means of investigating the foraging ecology of the Kaputar Pink Slug. There was a slight positive trend with height (mean sinuosity ratio at 3 m = 1.72 compared to 1.44 at 1 m), possibly suggesting a change in search behaviour from direct movements

Fig 4. Pied Currawong eating a Kaputar Pink Slug. Photo: J. Faris.

to a more area-restricted search (Wallin 1991). The study also determined that the slugs utilised a wide range of tree sizes for grazing, from less than 8 cm to over 60 cm diameter at breast height.

Bronze Rippled Pinwheel Snail *Cralopa kaputarensis* Stanisic, 1990

The Bronze Rippled Pinwheel Snail (Fig. 2B) is a member of the Charopidae, a family with a chiefly Gondwanan distribution including Australasia, southern Africa, sub-Antarctic islands and Central and South America, as well as south-east Asia, Indo-Pacific islands and western North America (Stanisic et al. 2010). Typical of many charopids, it is a small animal with a shell size of about 1.7 mm (Stanisic 1990; Stanisic et al. 2010). The species is endemic to Mount Kaputar, occurring in open forest above about 1200 m and dry rainforest remnants at lower elevation (Murphy and Shea 2015). It lives amongst grass, lichens and leaf litter and under fallen timber and loose rocks (Stanisic 1990; Hyman and Stanisic 2005; Stanisic et al. 2010). The species is thought to be herbivorous, feeding on decaying plant matter and fungi.

Kaputar Carnivorous Snail *Vitellidelos kaputarensis* Shea and Griffiths, 2010

The Kaputar Carnivorous Snail (Fig. 2C) is a member of the Rhytididae, a family of carnivorous snails with a Gondwanan distribution including Australia, New Zealand, New Caledonia, New Guinea and South Africa (Smith 1992; Herbert and Kilburn 2004; Stanisic et al. 2010). It is endemic to Mount Kaputar, with a distribution including open forest above about 1000 m and dry rainforest remnants at lower elevations (Murphy and Shea 2015). It has a dark yellow shell about 7 mm in diameter and lives in leaf litter and under fallen timber (Stanisic et al. 2010) and also under loose rocks (M. Murphy pers. obs.). Prey includes other land snail species.

Kaputar Keeled Snail *Thersites* sp. nov. "Kaputar"

The Kaputar Keeled Snail (Fig. 2D) is a member of the Camaenidae, a family considered a relatively recent arrival in Australia from south-east Asia about 15 million years ago and which has subsequently undergone a major radiation in Australia. It is the most westerly occurring of the *Thersites novaehollandiae*

Table 1. Extent of occurrence (EOO) and area of occupancy (AOO) estimates and number of locations for four Mount Kaputar endemic land snails.

	EOO	AOO	No. locations
Kaputar Pink Slug	545 km^2	280 km^2	2
Bronze Rippled Pinwheel Snail	309 km^2	136 km^2	4
Kaputar Carnivorous Snail	552 km^2	288 km^2	3
Kaputar Keeled Snail	348 km^2	196 km^2	3

species group (J. Stanisic pers. comm. in Murphy and Shea 2015) but is considerably smaller and more strongly keeled. It has a shell size of about 22 mm diameter and the animal is slate-grey in colour with a narrow pale mid-dorsal stripe. In comparison, *Thersites novaehollandiae* (*sensu stricto*) has a shell size of about 43 mm (Stanisic et al. 2010). A distance of about 160 km separates the Kaputar Keeled Snail from the nearest *Thersites novaehollandiae* populations east of Glen Innes and Armidale on the New England Tableland (Atlas of Living Australia). Another undescribed member of this species group is known from Warrabah NP, about 80 km south-east of Mount Kaputar (M. Shea Australian Museum pers. comm.). The Kaputar Keeled Snail has been assigned morpho-species code Camaenidae NE27 pending formal description and voucher material is available in museum collections (e.g. AMS C.79254, AMS C.478666, AMS C.478667, AMS C.481130, AMS C.481132 (Australian Museum) and QM MO32624 and QM MO32876 (Queensland Museum)). The first specimen was collected in 1967 by D.F. McMichael (Australian Museum). This undescribed species is endemic to Mount Kaputar NP, with all records restricted to open forest above about 1100 m and dry rainforest remnants at lower elevations (Murphy and Shea 2015). Animals have been found sheltering by day under loose rocks and fallen timber. *Thersites novaehollandiae* is partly arboreal when active at night, seen on tree trunks up to 6 m above the ground (Murphy 2007), but it is not known whether this behaviour is shared with the Kaputar Keeled Snail. Like other *Thersites* species (Parkyn et al. 2015), the Kaputar Keeled Snail is probably herbivorous, feeding on fungi and decaying plant matter.

CONSERVATION ASSESSMENTS

Extent of occurrence and area of occupation

EOO and AOO estimates for the four species are shown in Table 1 and EOO maps are shown in Figure 5A-D. EOO estimates for all four species are towards the lower end of the 100-5000 km^2 range for the *endangered* category under criterion B1 (IUCN 2017). All AOO estimates are within the 10-500 km^2 range for the *endangered* category under criterion B2 (IUCN 2017). All of the AOO estimates included much unsuitable habitat (low elevation dry eucalypt forest) as a result of the discontinuous distribution of highland areas at Mount Kaputar. A more accurate calculation using GIS mapping estimated the total highland area as approximately 107 km^2 above 1000 m AHD, 48 km^2 above 1100 m AHD and 21 km^2 above 1200 m. The precautionary inclusion of inferred habitat substantially increased EOO and AOO estimates for all four species. AOO estimates in particular are likely to be revised down as more information on where the species do and do not occur becomes available. Estimates for the Kaputar Pink Slug, for example, would be substantially reduced if the currently inferred presence of the taxon in the small disjunct highland areas in the north of Mount Kaputar NP and on freehold properties east of the park was discounted by field survey and the taxon was confirmed to only occur in and around the main highland area.

Number of locations

The number of locations for each species is also given in Table 1. All four species are known from fewer than five locations each and therefore meet criterion B(a) for the category *endangered* (IUCN 2017). The Kaputar Pink Slug is known from the highland area and from one lower elevation dry rainforest site on Oakey Creek. The Bronze Rippled Pinwheel Snail is known from the highland area and from lower elevation dry rainforest at Waa Gorge, Eulah Creek and the base of Mount Yulludunida. Another record of this species described as being from a location east of the Bark Hut camping area (QM49175) could not be reliably assessed as the record coordinates given are instead 500 m west of the camping area. The camping area is within 100 m of the 1200 m high elevation area and this record was therefore included within that location. The Kaputar Carnivorous Snail is known from the highland area and from dry rainforest at Waa Gorge and Sawn Rocks. The Kaputar Keeled

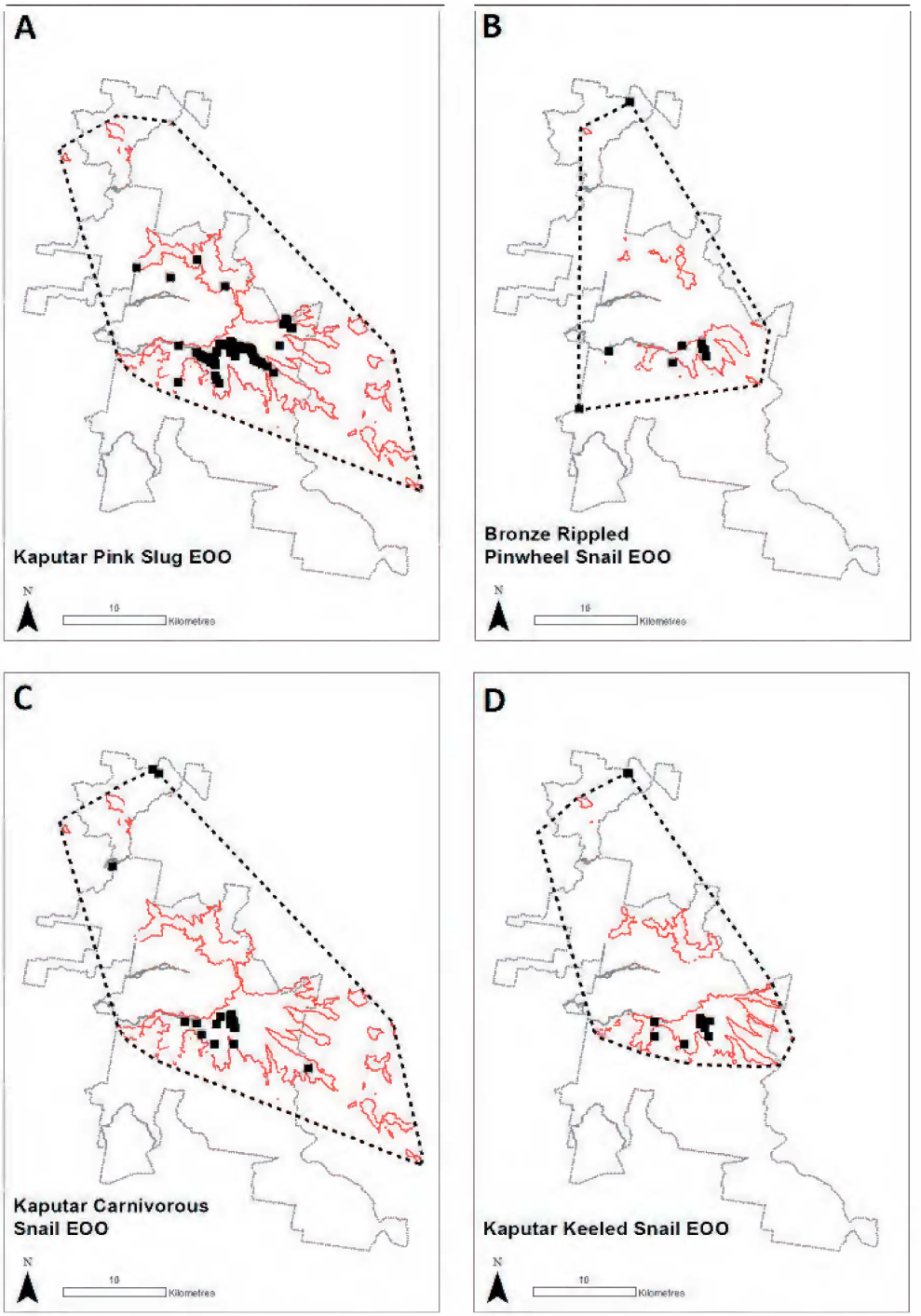

Fig 5. Maps of estimated extent of occurrence (shown as bold dashed line) for the four subject species. A, known sites of Kaputar Pink Slug and highland area over 1000 m. B, known sites of Bronze Rippled Pinwheel Snail and highland area over 1200 m. C, known sites of Kaputar Carnivorous Snail and highland area over 1000 m. D, known sites of Kaputar Keeled Snail and highland area over 1100 m.

Snail is known from the highland area and from dry rainforest at Waa Gorge and Black Mountain Creek.

Threats and continuing decline

A continuing decline is projected for all four species in EOO, AOO and the area, extent and quality of habitat due to a combination of threats, and the four species are therefore considered to meet criterion B(b)(i), (ii) and (iii) (IUCN 2017). Anthropogenic climate change is a major threat to the four species (Murphy and Shea 2015). Elevation-restricted montane ecosystems such as those found at Mount Kaputar are considered particularly susceptible to anthropogenic climate change (Brereton et al. 1995; Hughes 2003; Laurance et al. 2011) and Mount Kaputar is already marginal for sub-alpine ecosystems (NSW National Parks and Wildlife Service 2006). Many land snail species are considered particularly vulnerable to climate change because of poor dispersal ability and restricted distributions (Beltramino et al. 2015; Annagret and Ansart 2017). Land snail species restricted to higher elevation habitats are therefore of particular concern (Pearce and Paustian 2013). The four subject species are already highly restricted in distribution as a result of past climatic drying. Predicted global climate warming is likely to put these species at very high risk of extinction in the near future through further reduction and fragmentation of geographic extent and available habitat. Some land snail species are able to shift their elevation distribution in response to climate warming (Baur and Baur 2013); however, the four subject species already occupy the highest parts of Mount Kaputar, so a contraction from lower elevations must result in a net decrease in habitat area. Mount Kaputar NP has an elevation range of 1200 m and an associated temperature range of about 12°C. A 100 m vertical rise in the environmental envelope for these species at Mount Kaputar would reduce the available high-elevation area by about 55% (for 1000-1100 m) or 56% (for 1100-1200 m) and result in substantial further fragmentation. Based on projected climate impacts in Australia (e.g. Hughes 2003; Suppiah et al. 2007; Green et al. 2008), changes of this scale are considered possible by the latter half of the 21st century, and ongoing uncontrolled climate change could see the complete disappearance of these environmental envelopes.

Additional significant threats to the four subject species include fire and feral pigs (Murphy and Shea 2015). Fire is considered to be a major threat to land snails (Stanisic and Ponder 2004), with post-fire recovery of populations generally relying on survivors in unburnt refuge areas within the burnt area rather than recolonisation from the outside the fire edge (Kiss and Magnon 2003; Santos et al. 2009). Some of Mount Kaputar's sub-alpine vegetation communities have experienced fire frequencies above ecological thresholds and the risk of large intense wildfires extending into previously infrequently burnt wet eucalypt forests and dry rainforest refuges is likely to increase as a result of anthropogenic climate change (Murphy and Shea 2015). An increase in the frequency or intensity of fire events will put increased pressure on the subject species by reducing population recovery time and reducing the effectiveness of fire refugia respectively.

Feral pigs *Sus scrofa* (Suidae) are on ongoing problem in Mount Kaputar NP despite control efforts, damaging land snail habitat by digging over soil and leaf litter, turning logs and rocks and trampling ground vegetation, and are likely to prey directly on larger species such as the Kaputar Pink Slug and Kaputar Keeled Snail. Feral pigs have been found to significantly reduce litter cover and be responsible for both short and long-term reductions in the density of macro-invertebrates in mesic forest habitats (Taylor et al. 2011).

Roads can fragment habitat areas by acting as significant barriers to dispersal by land snails (Baur and Baur 1990). Roads within Mount Kaputar NP are necessary for park management activities including pest control and fire management but may act as barriers to the four subject species. Observation in April 2015 confirmed the risk to Kaputar Pink Slugs from vehicular traffic, with five crushed dead slugs (Fig. 6) found in a 15 m length of the main summit road on a rainy afternoon. Loss of habitat to development has been more substantial outside Mount Kaputar NP. Much of the high-elevation wet eucalypt forest on freehold properties bordering the eastern edge of the park has been cleared for agriculture and it is likely that the majority of off-park habitat for all four species has been lost.

CONSERVATION ACTIONS

The majority of remaining habitat for all four subject species is protected within Mount Kaputar NP, with additional protection through the declaration of much of the park as wilderness under the NSW *Wilderness Act 1987*. The high-elevation and dry rainforest land snail community at Mount Kaputar, including the four subject species and additional narrow-range endemic land snails, is also afforded protection through listing as an *endangered ecological community* under the NSW *Biodiversity*

Fig 6. Kaputar Pink Slug killed by motor vehicle. Photo: M.J. Murphy.

Conservation Act 2016, the first endangered land snail community listing in Australia (Murphy and Shea 2015). This listing has raised the public profile of Mount Kaputar's unique land snail community and the threats it faces and has increased the priority for funding and implementation of appropriate threat abatement and recovery actions. The major threat, however, (anthropogenic climate change) requires coordinated action at the global scale (Murphy and Shea 2015).

Key conservation actions required for the four subject species include further field survey to refine the known distributions, and computer modelling to investigate the likely local-scale influence of elevation, aspect and topography on predicted climate changes at Mount Kaputar. The composition of land snail assemblages has strong predictive value for identifying areas of long-term moisture stability which have functioned as refugia during previous periods of climate change (Stanisic 1990, 1994, 1997; Stanisic and Ponder 2004). A dual approach of computer modelling of local-scale climate change impacts and 'following the snails' will optimise the identification of potential future local-scale climatic refugia at Mount Kaputar. Scree slopes and boulder fields are also likely to serve as important climatic refuge areas (Couper and Hoskin 2008; Shoo et al. 2010; Reside et al. 2014; Stanisic et al. 2017) and should be mapped and included in this assessment. Once identified, these climatic refugia should then be a priority for fire management, feral pig control and other local conservation works.

The IUCN criteria can be applied to any taxonomic unit at or below the species level, including forms that are not yet formally described. However, the listing of undescribed species is discouraged by the IUCN unless there is general agreement that the undescribed form is a clearly circumscribed species, that work is underway to formally describe the species, that voucher material is available and that there is a clear conservation benefit in listing the undescribed form (IUCN 2017). The currently undescribed Kaputar Pink Slug met all of these requirements and was listed on the *IUCN Red List* in 2014 (Murphy 2014). The Kaputar Keeled Snail has been recognised as a valid undescribed species by Australian malacological experts and has been assigned a morphospecies code. However, while voucher material is available and listing would contribute to promoting the conservation of the taxon, no formal description of the species is currently underway, a reflection of the very large number of Australian land snails known to be awaiting description and the scarcity of malacologists able to undertake this work. Undescribed species of conservation concern should be a priority for taxonomic workers.

CONCLUSION

On the basis of the above, the Kaputar Pink Slug, Bronze Rippled Pinwheel Snail, Kaputar Carnivorous Snail and Kaputar Keeled Snail are all assessed as *endangered B1ab(i,ii,iii)+2ab(i,ii,iii)* under the IUCN criteria (IUCN 2017). This is consistent with the previous assessment for the Kaputar Pink Slug (Murphy 2014) but would be an elevation from the previous category of *data deficient* for the Bronze Rippled Pinwheel Snail (Mollusc Specialist Group 1996). All four taxa are narrow-range endemics with highly restricted relictual distributions and are threatened by anthropogenic climate change, frequent fire, feral pigs and habitat loss and fragmentation. As noted above, formal taxonomic description is required for two of the species.

The vividly-coloured Kaputar Pink Slug has significant public appeal as an iconic flagship species for recognition of the major global threat to biodiversity posed by anthropogenic climate change. IUCN listing of additional Mount Kaputar land snail species as recommended here would assist in promoting recognition of the significant conservation value of Mount Kaputar and similar volcanic high-elevation climatic refuges for Australia's unique land snail fauna.

ACKNOWLEDGEMENTS

Thanks to Anton Groeneveld and Michael Heinze for providing slug records and Michael Shea for providing Figure 2B.

REFERENCES

Annegret, N. and Ansart, A. (2017). Conservation at a slow pace: terrestrial gastropods facing fast-changing climate. *Conservation Physiology* 5(1), cox007. DOI 10.1093/conphys/cox007

Atlas of Living Australia website at http://www.ala.org.au. Accessed 29 July 2018.

Baur, A. and Baur, B. (1990). Are roads barriers to dispersal in the land snail *Arianta arbustorum*? *Canadian Journal of Zoology* **68**, 613-617.

Baur, A. and Baur, B. (2013). Snails keep the pace: shift in upper elevation limit on mountain slopes as a response to climate warming. *Canadian Journal of Zoology* **91**, 596-599.

Beltramino, A.A., Vogler, R.E., Gutiérrez Gregoric, D.E. and Rumi, A. (2015). Impact of climate change on the distribution of a giant land snail from South America: predicting future trends for setting conservation priorities on native malacofauna. *Climatic Change* **131(4)**, 621-633.

Brereton, R., Bennett, S. and Mansergh, I. (1995). Enhanced greenhouse climate change and its potential effect on selected fauna of south-eastern Australia: a trend analysis. *Biological Conservation* **72(3)**, 339-354. DOI 10.1016/0006-3207(94)00016-J

Burton, D.W. (1980). Anatomical studies on Australian, New Zealand and sub-Antarctic Athoracophoridae (Gastropoda: Pulmonata). *New Zealand Journal of Zoology* **7**, 173-198.

Couper, P.J. and Hoskin, C.J. (2008). Litho-refugia: the importance of rock landscapes for the long-term persistence of Australian rainforest fauna. *Australian Zoologist* **34(4):** 554-560.

Green, K., Stein, J.A. and Driessen, M.M (2008). The projected distributions of *Mastacomys fuscus* and *Rattus lutreolus* in south-eastern Australia under a scenario of climate change: potential for increased competition? *Wildlife Research* **35(2)**, 113-119. DOI 10.1071/WR07055

Herbert, D. and Kilburn, D. (2004). *Field Guide to the Land Snails and Slugs of Eastern South Africa*. Natal Museum, Pietermaritzburg, South Africa.

Hughes, L. (2003). Climate change and Australia: Trends, projections and impacts. *Austral Ecology* **28(4)**, 423-443. DOI 10.1046/j.1442-9993.2003.01300.x

Hunter, J.T. and Alexander, J. (2000). Vegetation and floristics of Mount Kaputar National Park (central and northern portions). Unpublished report to NSW National Parks and Wildlife Service, Narrabri, NSW, Australia.

Hyman, I.T. and Stanisic, J. (2005) New charopid land snails chiefly from limestone in eastern New South Wales. *Memoirs of the Queensland Museum* **50**, 219-302.

International Union for the Conservation of Nature (2012). *IUCN Red List Categories and Criteria Version 3.1 2nd edition.* Available online at: http://www.iucnredlist.org. Accessed 24 February 2019.

International Union for the Conservation of Nature (2017). *Guidelines for Using the IUCN Red List Categories and Criteria* (Version 13). Prepared by the Standards and Petitions Subcommittee. Available online at: http://www.iucnredlist.org/documents/RedListGuidelines.pdf. Accessed 24 February 2019.

Kiss, L. and Magnin, F. (2003) The impact of fire on some Mediterranean land snail communities and patterns of post-fire recolonization. *Journal of Molluscan Studies* **69**, 43-53.

Laurance, W.F., Dell, B., Turton, S.M., Lawes, M.J., Hutley, L.B., McCallum, H., Dale, P., Bird, M., Hardy, G., Prideaux, G., Gawne, B., McMahon, C.R., Yu, R., Hero, J.-M., Schwarzkopf, L., Krockenberger, A., Setterfield, S.A., Douglas, M., Silvester, E., Mahony, M., Vella, K., Saikia, U., Wahren, C.-H., Xu, Z., Smith, B. and Cocklin, C. (2011). The 10 Australian ecosystems most vulnerable to tipping points. *Biological Conservation* **144**, 1472-1480.

Martin, H.A. (2006) Cenozoic climatic change and the development of the arid vegetation in Australia. *Journal of Arid Environments* **66**, 533-563.

Mollusc Specialist Group (1996). *Cralopa kaputarensis*. The IUCN Red List of Threatened Species 1996. DOI 10.2305/IUCN.UK.1996.RLTS.T5469A11175761.en. Downloaded on 27 July 2018.

Murphy, M.J. (2007). The diverse land snail community of Bruxner Park on the north coast of New South Wales, Australia. *The Victorian Naturalist* **124(5)**, 306-309.

Murphy, M. (2014). *Triboniophorus* sp. nov. "Kaputar". *The IUCN Red List of Threatened Species 2014*. DOI 10.2305/IUCN.UK.2014-3.RLTS.T55242781A55243154.en. Downloaded on 24 February 2019.

Murphy, M.J. and Shea, M. (2015). Survey of the land snail fauna (Gastropoda: Pulmonata) of Mount Kaputar National Park in northern inland New South Wales, Australia, including a description of the listing of Australia's first legally recognised endangered land snail community. *Molluscan Research* **35(1)**, 51-64.

NSW National Parks and Wildlife Service (2006). Mount Kaputar National Park Plan of Management. NSW National Parks and Wildlife Service, Sydney, NSW. Available online at https://www.environment.nsw.gov.au. Downloaded on 10 August 2018.

Parkyn, J., Challisthianagara, A., Brooks, L., Specht, A., McMullan-Fisher, S. and Newell, D. (2015). The natural diet of the endangered camaenid land snail *Thersites mitchellae* (Cox, 1864) in northern New South Wales, Australia. *Australian Zoologist* **37:** 343-349.

Parkyn, J. and Newell, D.A. (2013). Australian land snails: a review of ecological research and conservation approaches. *Molluscan Research* **33**, 116-129.

Pearce, T.A. and Paustian, M.E. (2013). Are temperate land snails susceptible to climate change through reduced altitudinal ranges? A Pennsylvania example. *American Malacological Bulletin* **31(2)**, 213-224. DOI 10.4003/006.031.0201.

Ponder, W.F. (1997). Conservation status, threats and habitat requirements of Australian terrestrial and freshwater mollusca. *Memoirs of the Museum of Victoria* **56(2)**, 421-430.

Porteners, M.F. (1997). Vegetation survey of sub-alpine communities in Mount Kaputar National Park. Unpublished report to NSW National Parks and Wildlife Service, Narrabri, NSW, Australia.

Porteners, M.F. (1998). Vegetation survey of Mount Kaputar National Park (southern portion). Unpublished report to NSW National Parks and Wildlife Service, Narrabri, NSW, Australia.

Reside, A.E., Welbergen, J.A., Phillips, B.L., Wardell-Johnson, G.W., Keppel, G., Ferrier, S., Williams, S.E. and Vanderwal, J. (2014). Characteristics of climate change refugia for Australian biodiversity. *Austral Ecology* **39(8):** 887-897.

Santos, X., Bros, V. and Mino, A. (2009). Recolonization of a burned Mediterranean area by terrestrial gastropods. *Biodiversity and Conservation* **18**, 3153. DOI 10.1007/s10531-009-9634-2.

Shea, M. (1992) Some land snails of the Warrumbungles. *Sydney Sheller* **August 1992**, 9.

Shoo, L.P., Storlie, C., Williams, Y.M. and Williams, S.E. (2010). Potential for mountaintop boulder fields to buffer species against extreme heat stress under climate change. International Journal of Biometeorology **54(4)**, 475-478. DOI 10.1007/s00484-009-0286-4.

Slatyer, C., Ponder, W., Rosauer, D. and Davis, L. (2007). Between a rock and a dry place: land snails in arid Australia. In: Dickman, C., Lunney, D. and Burgin, S. (Eds), *Animals of Arid Australia: out on their own?* Transactions of the Royal Zoological Society of New South Wales, Mosman, NSW, pp. 30-41.

Smith, B.J. (1992). *Zoological Catalogue of Australia Vol. 8: Non-Marine Mollusca*. Australian Government Publishing Service, Canberra.

Stanisic, J. (1990). Systematics and biogeography of eastern Australian Charopidae (Mollusca, Pulmonata) from subtropical rainforests. *Memoirs of the Queensland Museum* **30**, 1-241.

Stanisic, J. (1994). The distribution and patterns of species diversity of land snails in eastern Australia. *Memoirs of the Queensland Museum* **36**, 207-214.

Stanisic, J. (1997). An area of exceptional land snail diversity; the Macleay valley, north-eastern New South Wales. *Memoirs of the Museum of Victoria* **56(2)**, 441-448.

Stanisic, J. and Ponder, W.F. (2004). Forest snails in eastern Australia – one aspect of the other 99%. Pp. 127-149 in *Conservation of Australia's Forest Fauna* (2nd edition). Edited by D. Lunney. Royal Zoological Society of NSW, Mosman, NSW.

Stanisic, J., Shea, M., Potter, D. and Griffiths, O. (2010) *Australian Land Snails Volume 1: A Field Guide to Eastern Australian Species*. Bioculture Press, Mauritius.

Stanisic, J., Shea, M., Potter, D. and Griffiths, O. (2017) *Australian Land Snails Volume 2: A Field Guide to Southern, Central and Western Species*. Bioculture Press, Mauritius.

Suppiah, R., Hennessy, K.J., Whetton, P.H., McInnes, K., Macadam, I., Bathols, J., Ricketts, J. and Page, C.M. (2007). Australian climate change projections derived from simulations performed for the IPCC 4th Assessment Report. *Australian Meteorological Magazine* **56**, 131-152.

Sutherland, F.L. (2011). Diversity within geodiversity, underpinning habitats within New South Wales volcanic areas. *Proceedings of the Linnean Society of New South Wales* **132**, 37-54.

Taylor, D.L., Leung, L.K.-P. and Gordon, I.J. (2011). The impact of feral pigs (*Sus scrofa*) on an Australian lowland tropical rainforest. *Wildlife Research* **38**, 437-445.

Wallin, H. (1991). Movement patterns and foraging tactics of a caterpillar hunter inhabiting alfalfa fields. *Functional Ecology* **5**, 740-749.